

Magnets and Accelerators

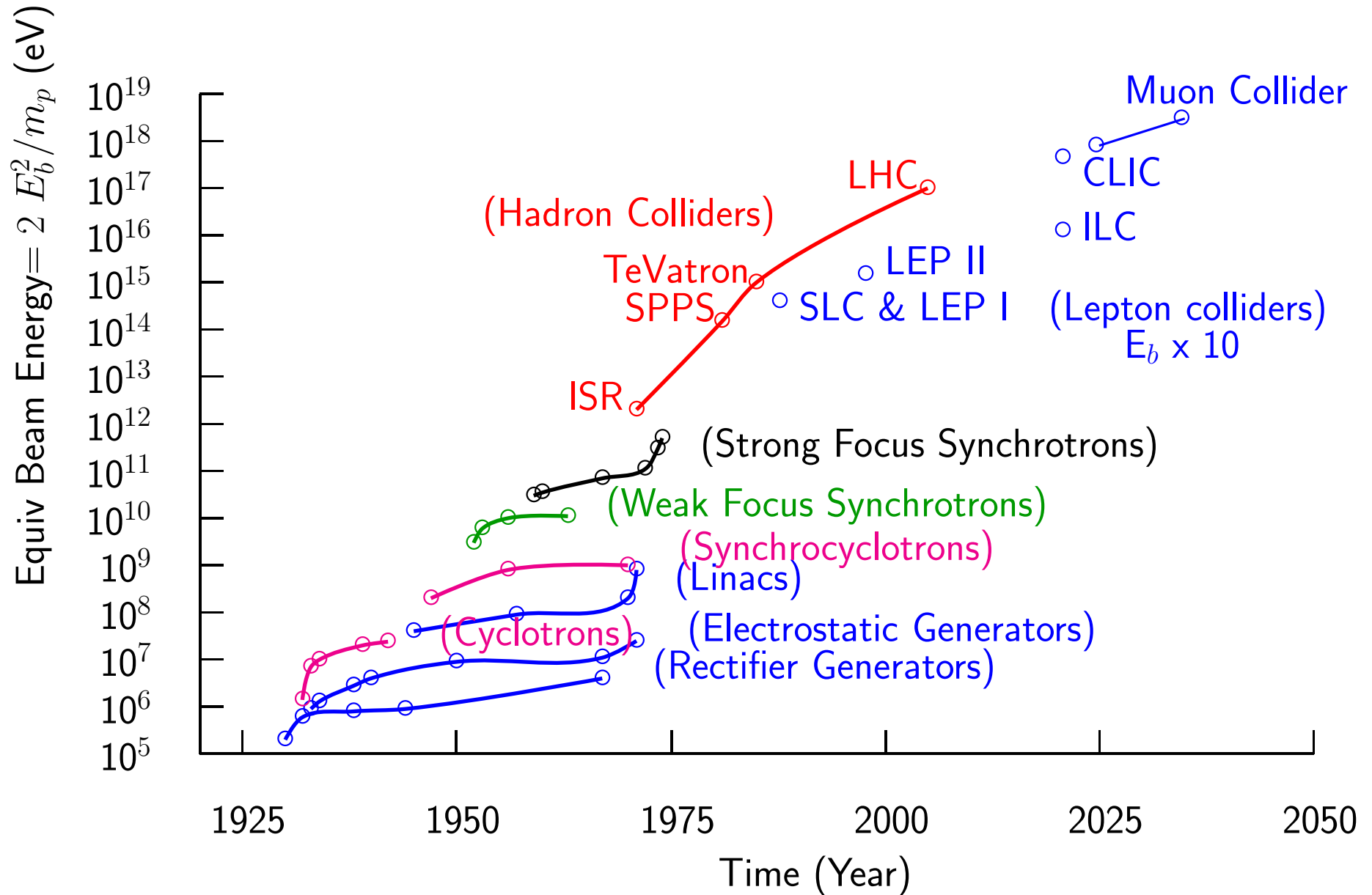
R. B. Palmer

Rahmfest
18/12/2007

- Introduction
- Strong Focusing
- Colliders
- The Future



Blewett (Livingston) Plot

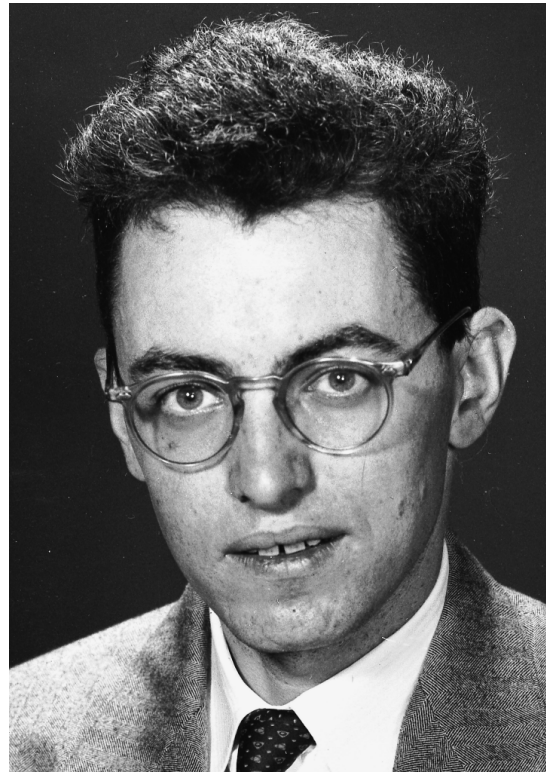


STRONG FOCUSING

The 1952 Revolution: Strong Focusing



Livingston



Courant



Snyder

Strong focusing, discovered at Brookhaven, made the modern accelerators possible

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The Alternating Gradient Synchrotron (AGS)



In 1960 the AGS started operation. It has been one of the most productive "Engines of Discovery" ever built, and it is still running as an injector into RHIC.

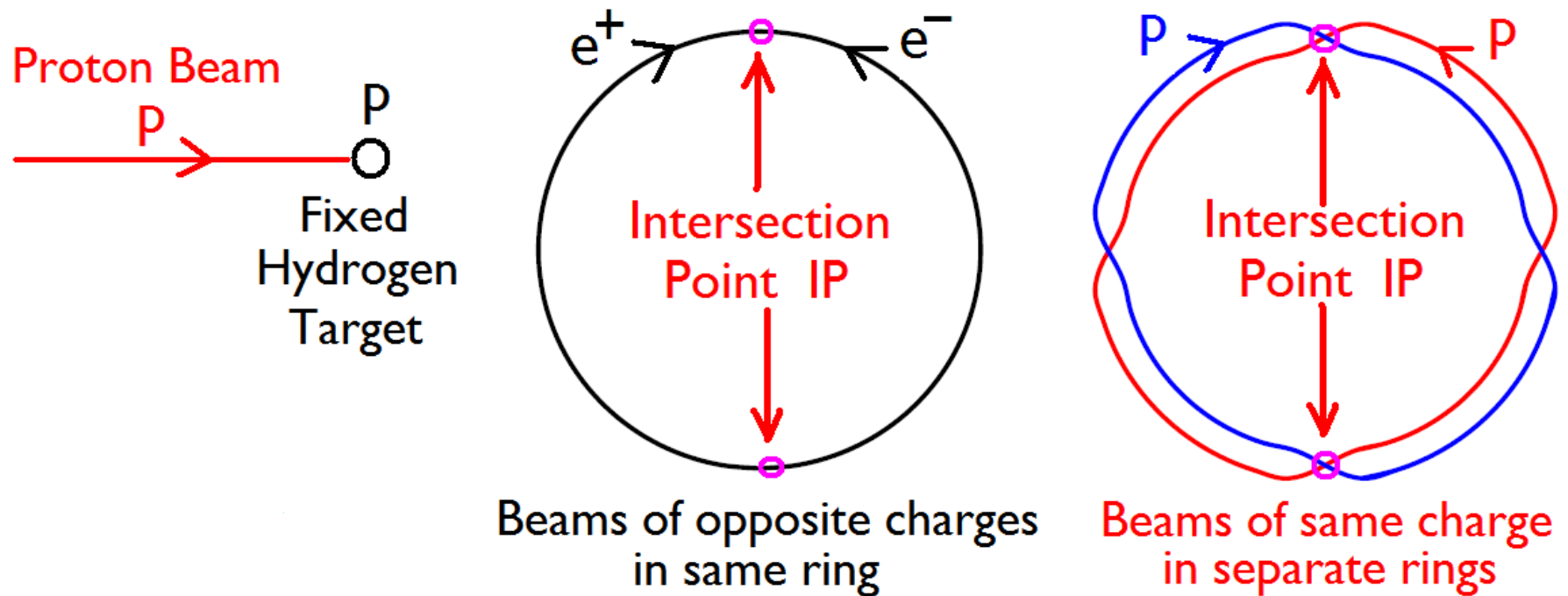
Fermi Lab

- The gentleman's agreement was that LBNL (Berkeley) would get the next machine at 200 GeV.
- But there never were any gentlemen. Robert Wilson said he could build a 400 GeV machine for the same money. Illinois bid for the project and won.
- Fermilab was founded and the 400 GeV machine was built
- In 1971, with "un-used" funds from the 400 GeV project Wilson built a superconducting energy saver



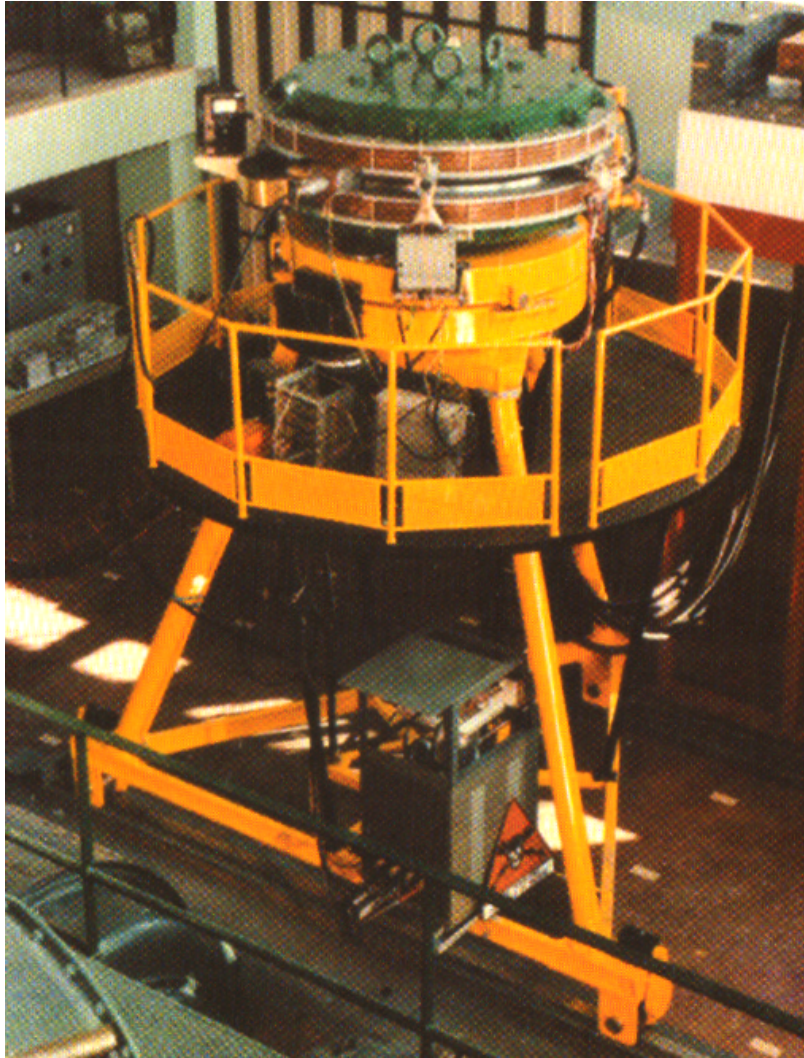
COLLIDERS

Colliders: The next new technology

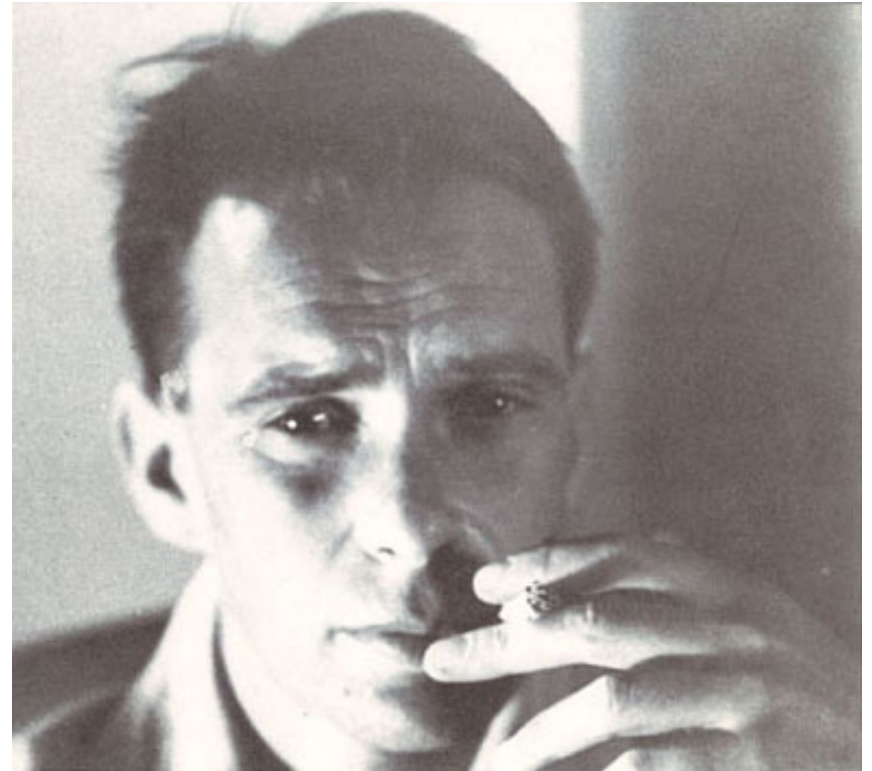


- From relativity this gives huge gains in effective energy
- In principle one could collide protons and anti-protons, but there was no known way to 'cool' the anti-protons for luminosity
- There was even doubt about getting sufficient luminosity with proton-proton

1961 First Collider: an $e^+ - e^-$ Single Ring Machine



AdA at Frascati, Italy



Touschek

- Inject e^+ Flip then e^-
- Beam lost when flipped !
- Trouble with gravity ?

1969 First p-p (Two Ring) Collider: 30 GeV ISR



ISR at CERN, Switzerland



Johnsen
Later at BNL

The ISR, built with incredible care, worked incredibly well.

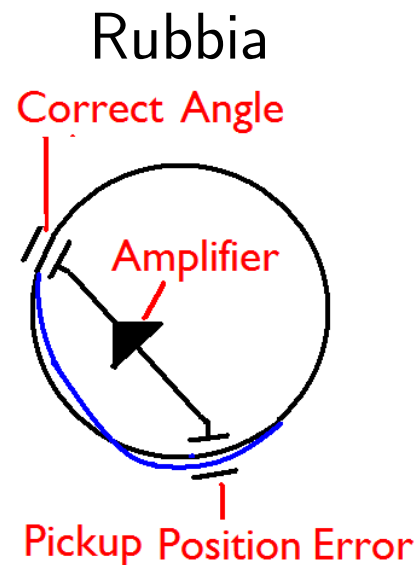
Leading, later, to the decision for BNL to build a 400 GeV ISA to be called "Isabelle", but the possibility of $\bar{p} - p$ gave competition.

Stochastic Cooling & 1st Proton-Antiproton Collider: 400 GeV SPPS at CERN

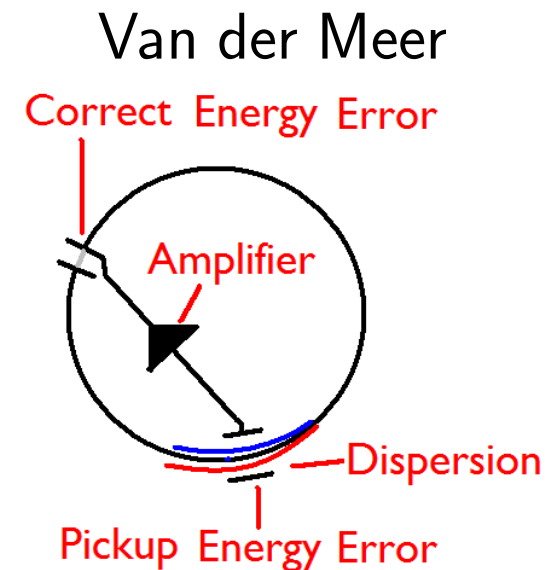
Budker had invented Electron Cooling in 1967 and tested it in 1974, but it was not adequate to cool antiprotons for a collider

In 1976 Van der Meer invented Stochastic Cooling for transverse amplitudes.

In a workshop at BNL, I suggested the extension to cooling momentum, and was surprised to find myself acknowledged by Carlo



Van der Meer



Palmer

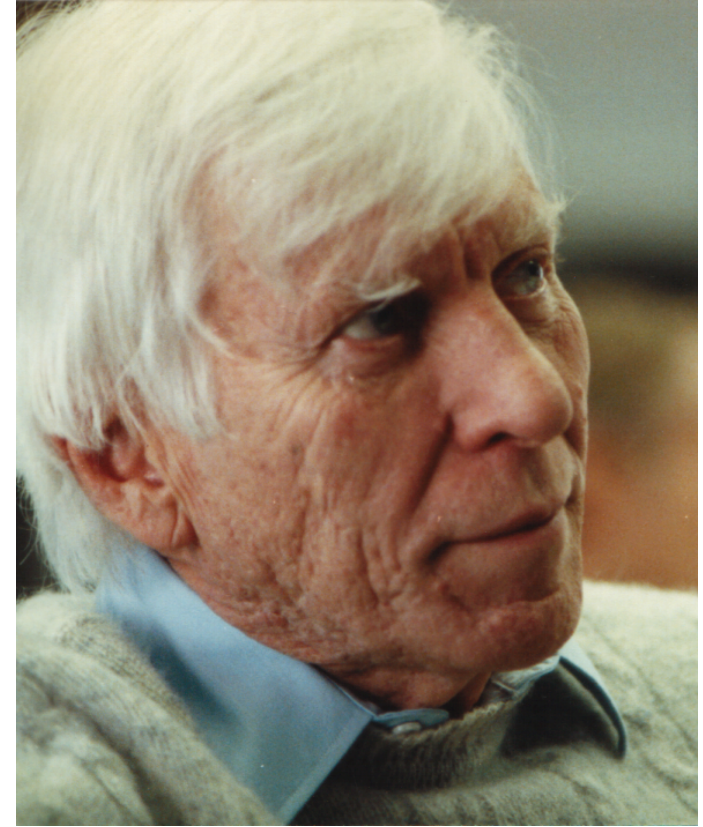
A proton-anti-proton collider in US: The TeVatron



Wilson



Edwards

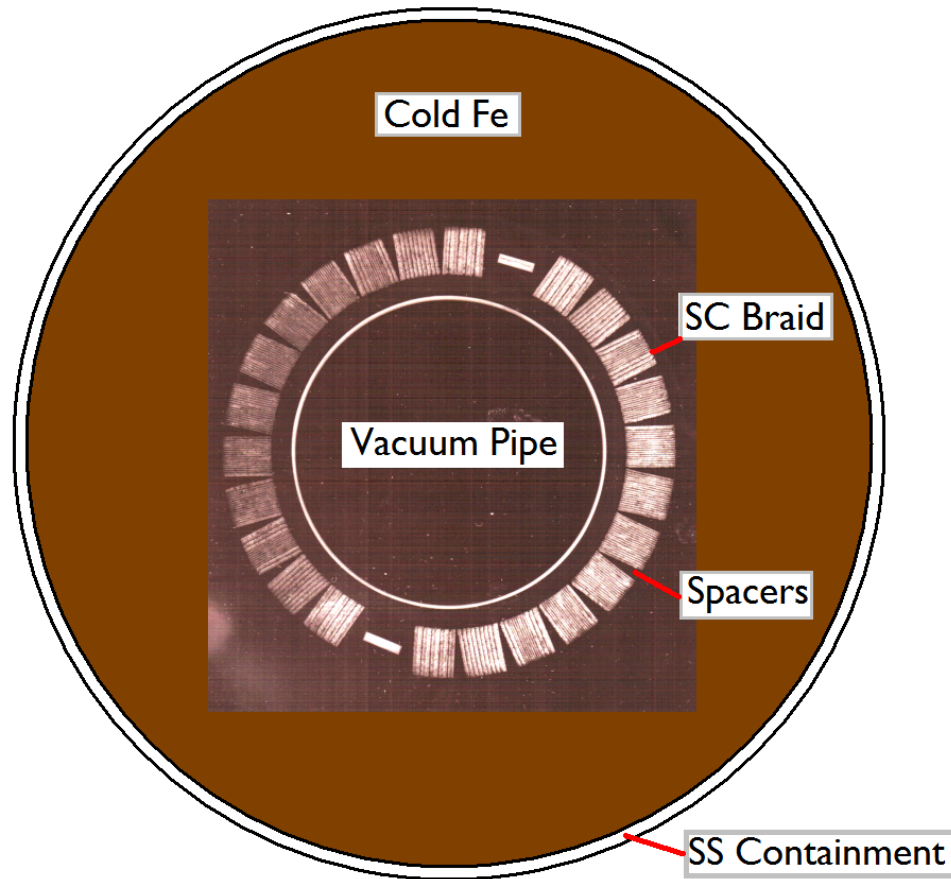


Tollestrup

The TeVatron ran (1983) for fixed target physics at near 900 GeV. With stochastic cooling, it could be converted (1994) to an antiproton-proton collider like the SPPS, but at $2 \times$ the energy

This became a direct competitor with Isabelle

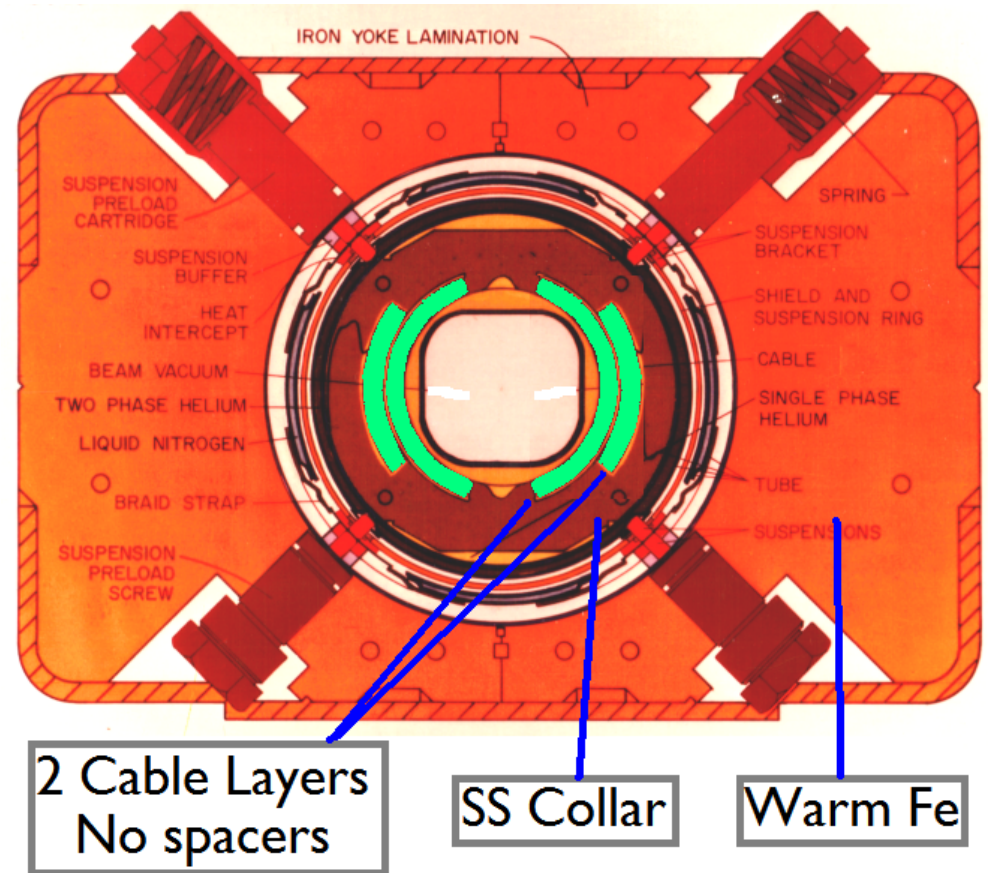
Isabelle at BNL vs. TeVatron at FNAL



Isabelle

BNL

Proton-proton
High Luminosity
400 GeV



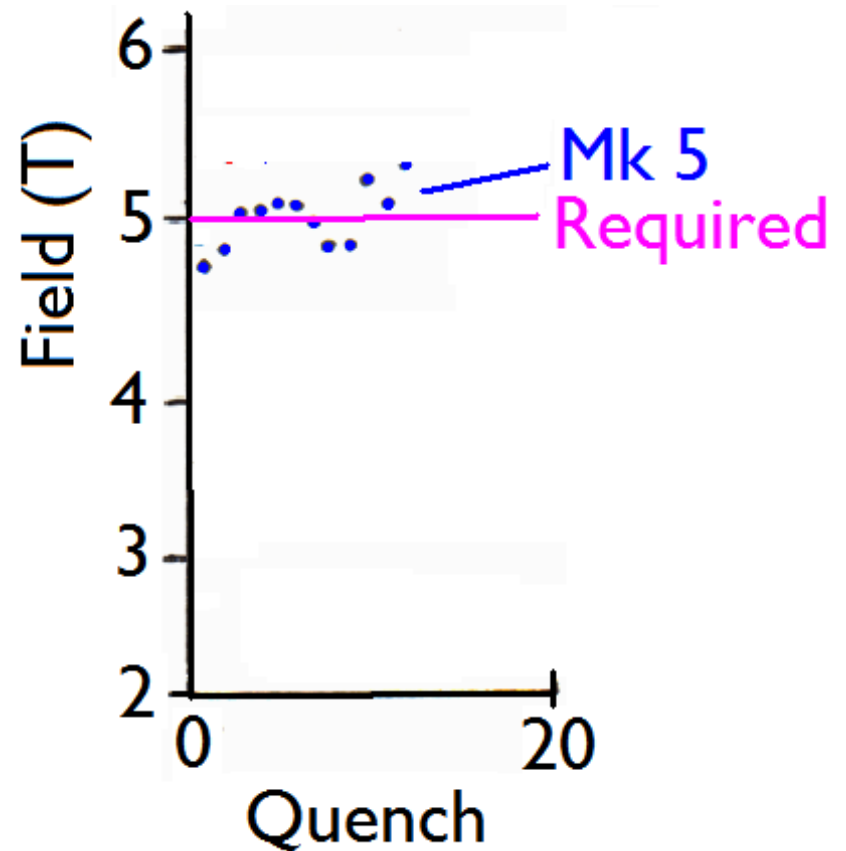
TeVatron

FNAL

Proton-antiproton
Low Luminosity
900 GeV

Isabelle Magnet Performance at BNL

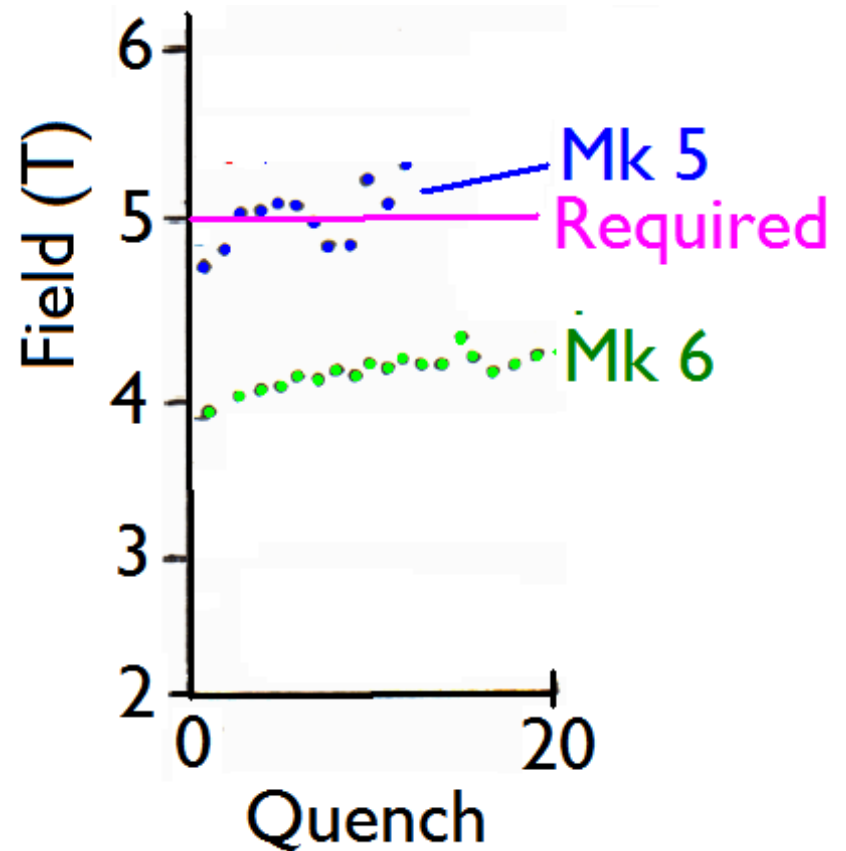
After some initial magnet success at BNL, the design field was raised from 4 to 5 T. Production was then handed off to Grumman. By the 5th industrial magnet, the desired field was reached.



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But the next did not do so well



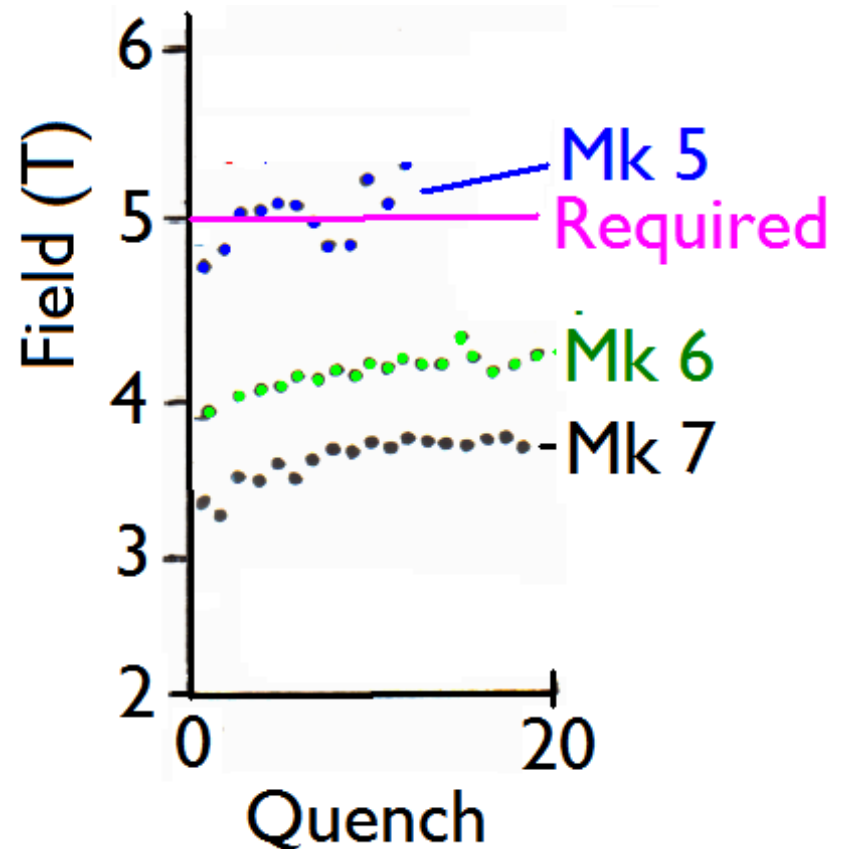
Isabelle Magnet Performance at BNL

After some initial magnet success at BNL, the design field was raised from 4 to 5 T. Production was then handed off to Grumman. By the 5th industrial magnet, the desired field was reached.

But the next did not do so well

And the next did worse.

Mk5 was never reproduced.



Lab management kept claiming that it now understood the problem, and that the next magnet would prove it. Those who claimed otherwise were told to keep quiet, but eventually a committee under Forsythe was formed to study the problem.

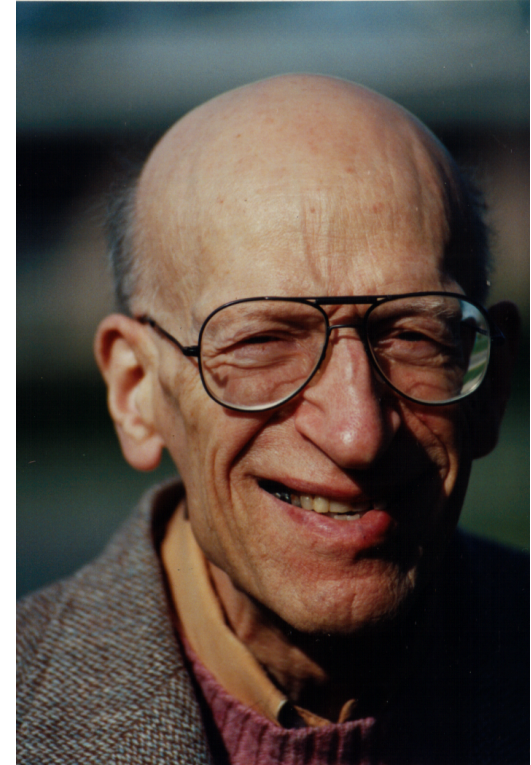
Palmer Magnet



Goodzeit



Samios

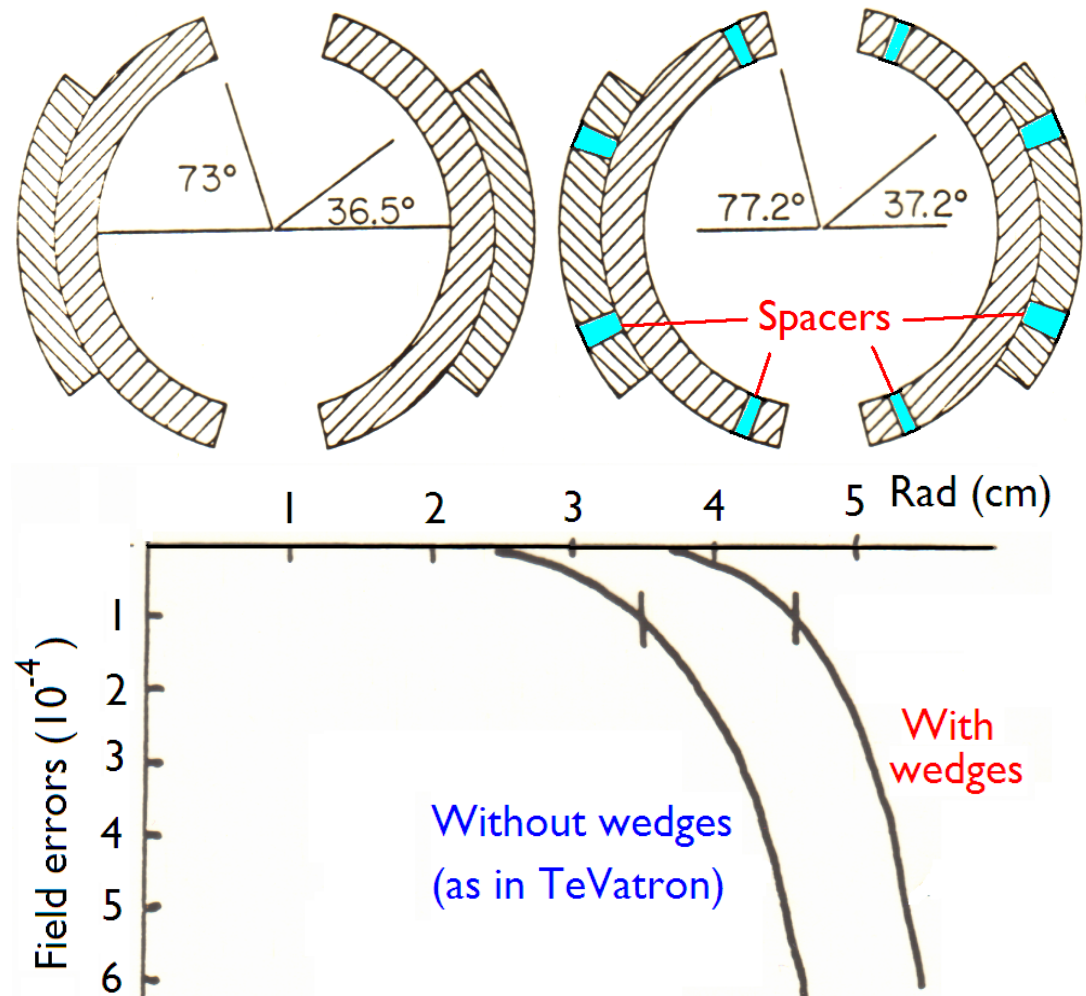


Shutt

The committee agreed that a new approach was needed, but not on what that approach should be. A small group of us in Physics believed we had the answer. Samios could provide only 30 k\$, about 1/10th of what was needed, but we started anyway.

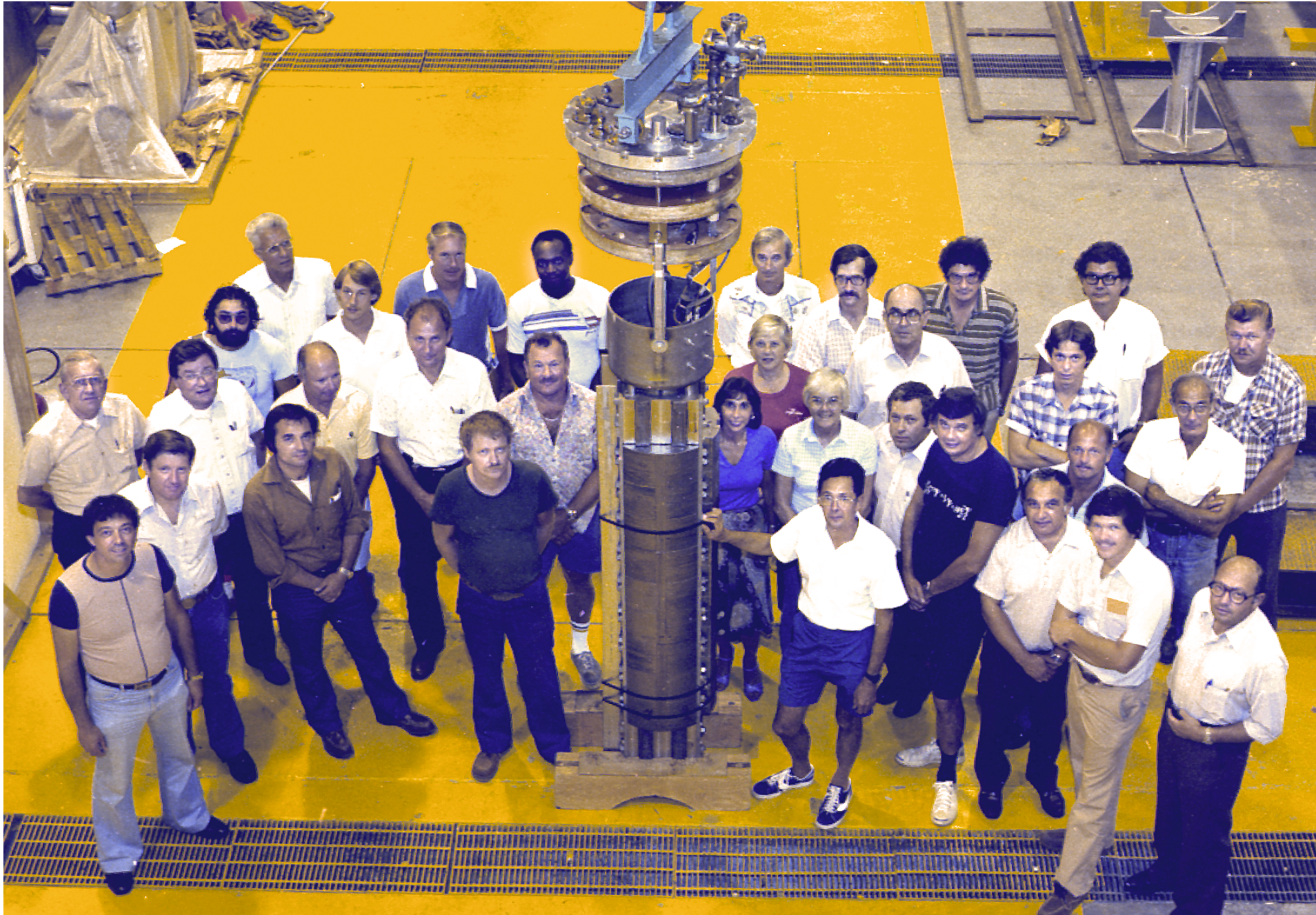
Palmer Magnet

- Use 2 layers of Cable (as in TeVatron) free from friends
- Add spacers (as in Isabelle) to get required field quality
- Use Cold Iron (as in Isabelle) to support coil forces
- Split the iron and apply pre-compression with bolts (new)

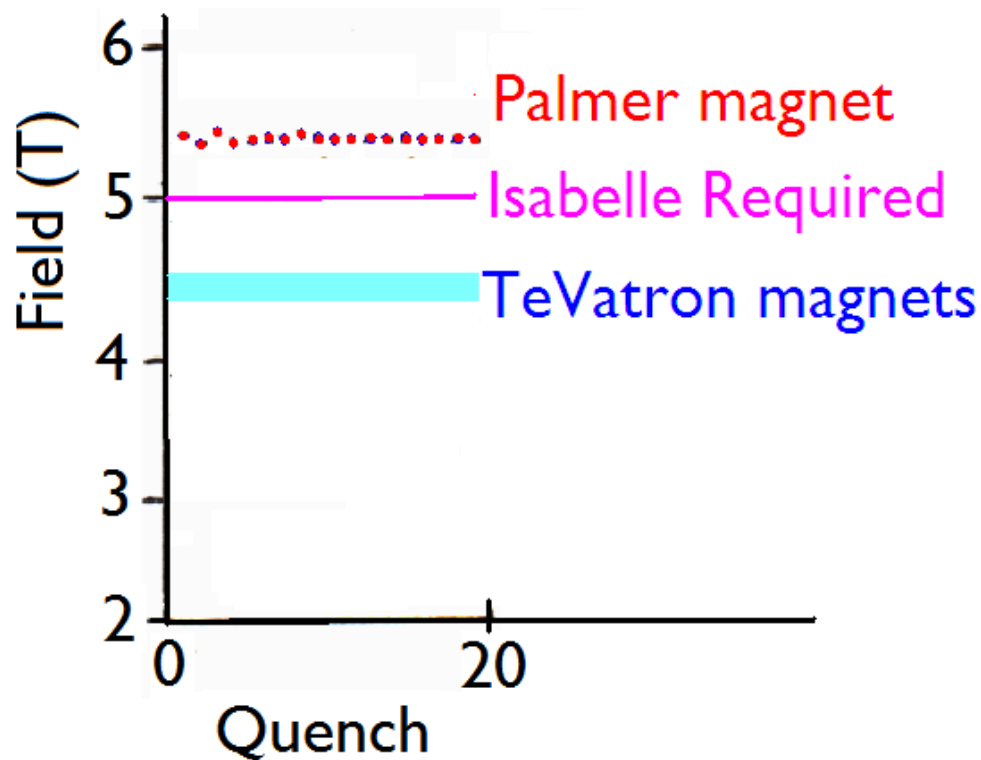


Without priority in the BNL shops, we machined parts at the MIT Magnet Lab (Marsden). We also had a secret priority with BNL shop's Bob Lehn. Marsden, conveniently, did not send BNL the bills till after the magnet was complete. The total was nearly 300 k\$!

6 Months later we tested our prototype



It worked perfectly

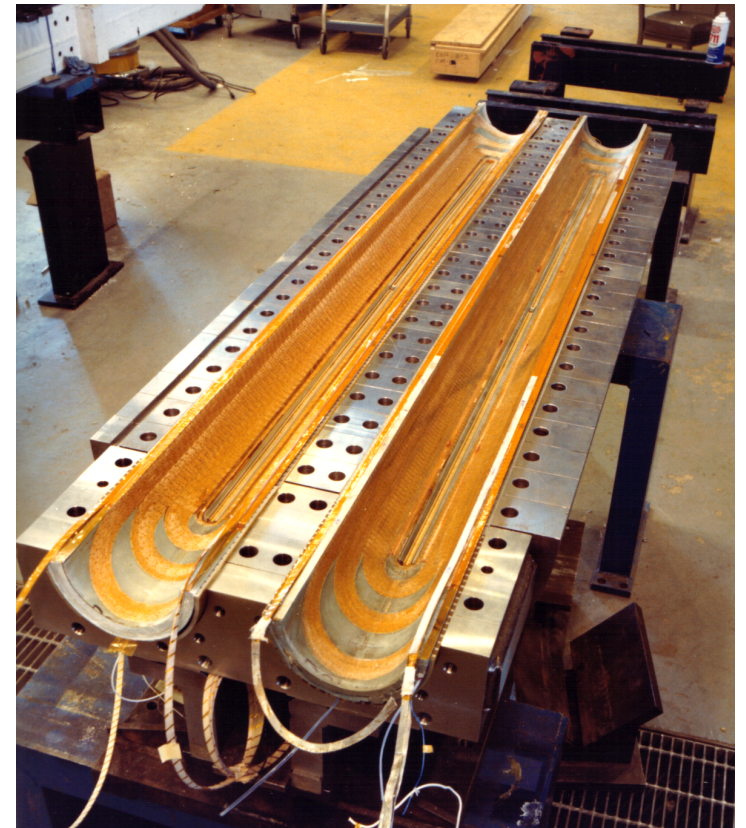
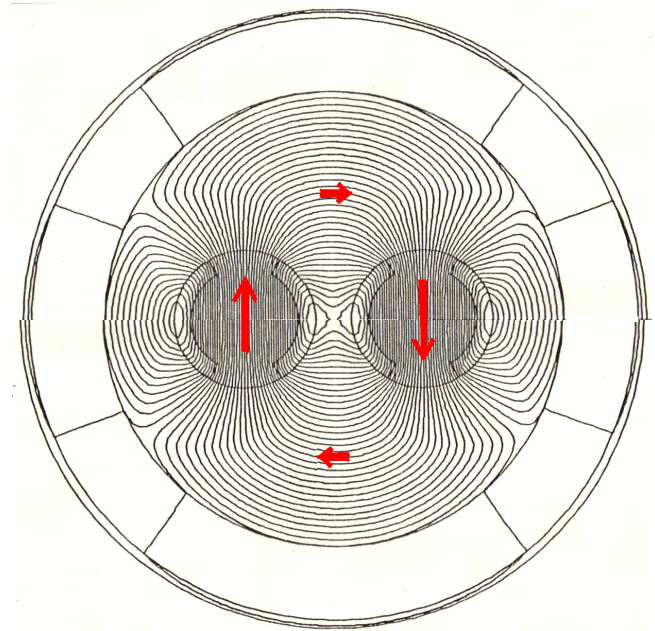


- Conductor as in TeVatron
BUT
- Higher field quality
from use of wedges
- Higher field
because of cold iron

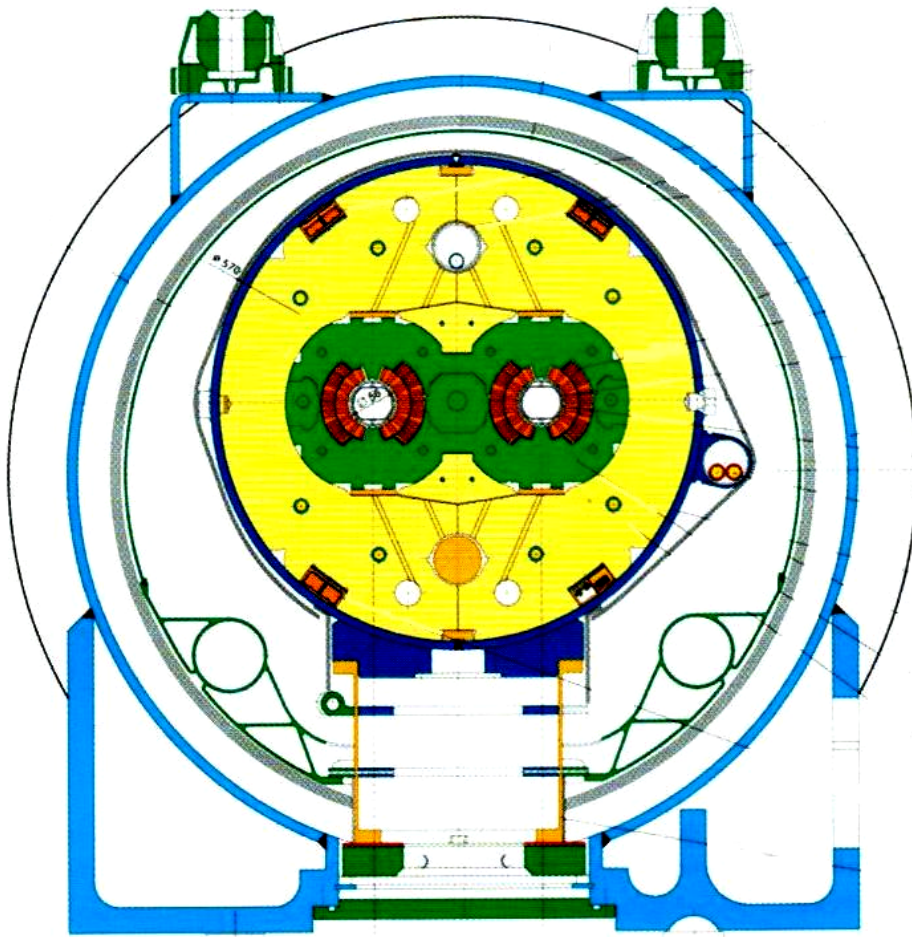
- Samios became the Lab Director
- Nobody worried about the 300 k\$
- Spacers and cold iron became standard
- Yet it was too late. Isabelle was canceled, but we got RHIC

Another idea not lost: 2 in 1

- Mount 2 dipoles in one Fe yoke
- Uses less iron
- And less superconductor
- Lower cost
- Built prototypes for Isabelle
- Isabelle rejected them
- Built prototypes for SSC
- SSC rejected them
- But the LHC chose them
If LHC fails, you know who to blame



CERN Switzerland 7 TeV Large Hadron Collider (LHC)



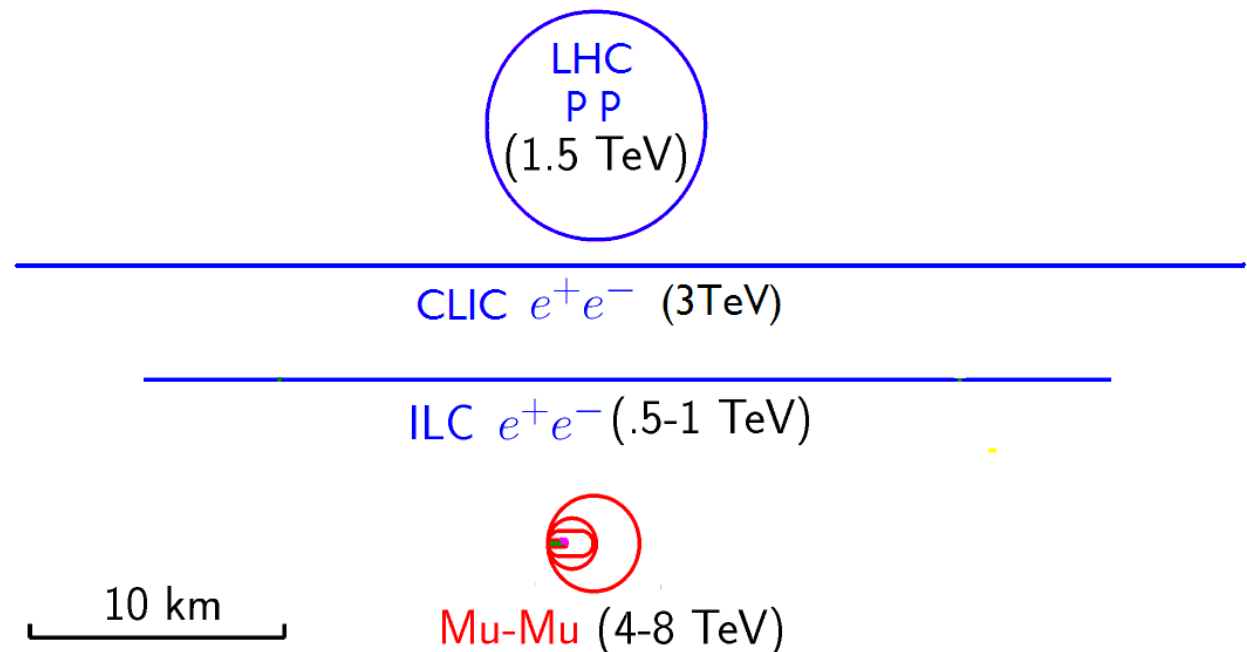
- BNL also made IR magnets for LHC
- Is helping in commissioning
- And working on upgrades (LARP)

FUTURE MACHINES

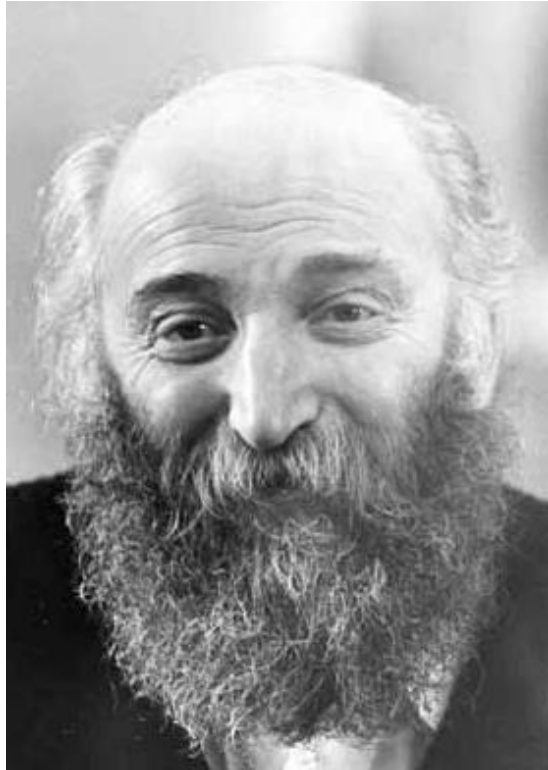
Energy Frontier Options

	km	len/circ	c of E TeV	effective TeV
c.f. LHC	p p	27	14	1.5
ILC	e^+e^-	41	0.5	0.5
LHC Doubler	p p	27	28	3
CLIC	e^+e^-	48	3	3
Muon	$\mu^+\mu^-$	12	4-8	4-8

- ILC is not a frontier machine and not cheap
- CLIC is even longer and could be more expensive
- Could muons be cheaper?



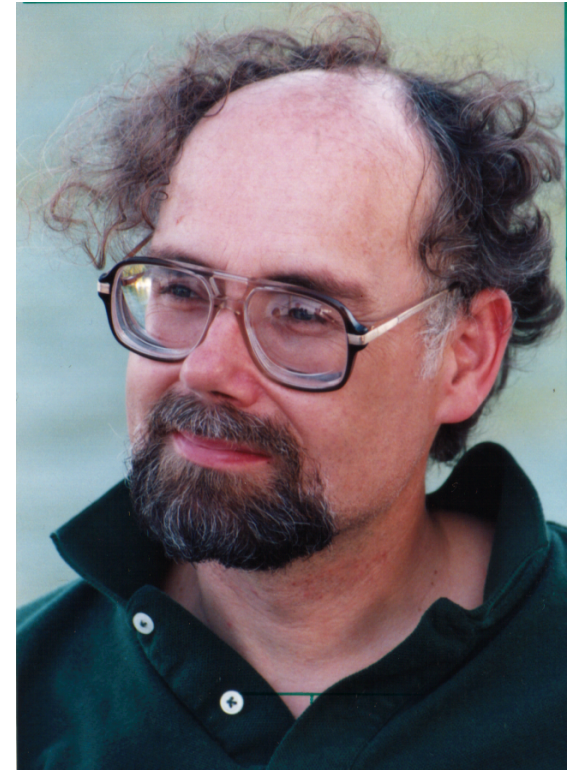
Muon Colliders



Budker



Skrinsky

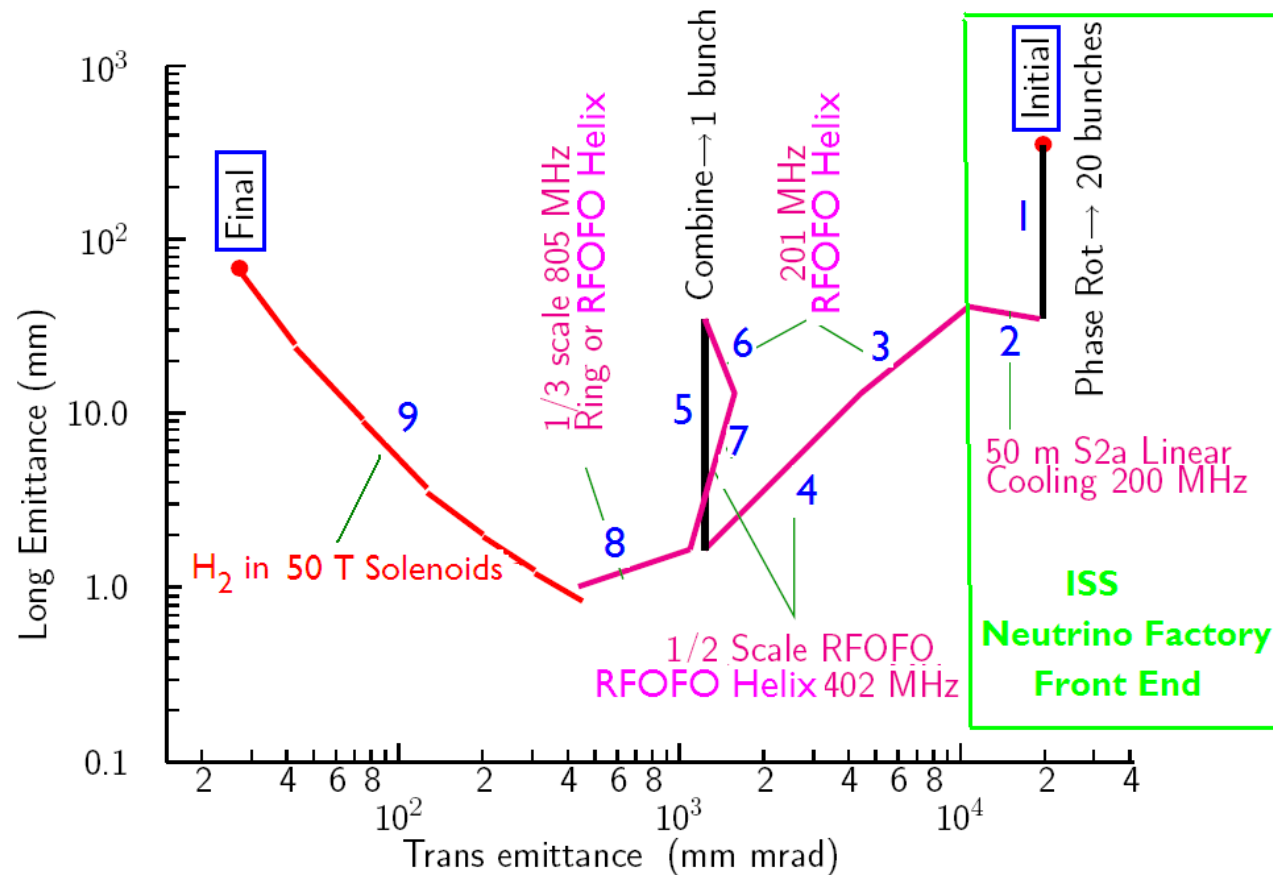


Neuffer

Proposed by Budker in 1969, with the needed ionization cooling by Skrinsky and Parkhomchuk in 1981. Neuffer gave an outline in 1983. The US Muon Collider Collaboration was formed in 1997. FNAL formed its Muon Collider Task Force in 2006. Much recent progress has been made.

Why Muons?

- Muons are point like, so their full energy counts
- And they can be bent, making their colliders much smaller
- But life is hard
- Muons are made very diffusely
- And they do not live very long



The problem, as with antiprotons, is cooling the muons. Stochastic cooling is too slow, so we have to use **Ionization Cooling**.

- Complete scheme outlined, but much design and experimental work remaining
- Feasibility study, including cost estimate, aimed for 2012

▪

”What if I break a leg ?”